THE IMPROVEMENT OF VISUAL ACUITY BY CONDITIONING THE INTRINSIC AND EXTRINSIC EYE MUSCLES

by

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REVIEW OF STUDY OF MUSCLE BALANCE

Introduction

The study of the eye, at least from the practicioner's view point, may be divided into three parts: Pathology, Refraction, and Muscle Balance. Although there is a close inter-relationship among these three main divisions, each in itself is almost a field of specialty.

Since the study of ocular pathology is concerned chiefly with diseased conditions of the eye, the medical curriculum and extensive post-graduate study in ophthalmology are necessary prerequisites for work in this field. It should also be noted that skill in diagnosis as well as a delicate technique in surgery are among the prime essentials in this work.

Refraction, or the prescribing of lenses for correcting anatomical and functional deficiencies, is dependent upon a knowledge of physics, of mathematics, and of the physiology of the eye. Practical knowledge of the mechanics of lens manufacturing and training in the relatively new science of illumination are also essential for this

work. Refraction is by far the most important single study in the field of eye work today, for investigations have shown that seven out of ten people have refractive defects, and it is a well known fact that everyone past the age of forty must eventually wear glasses (5).

Muscle balance is concerned with the functions of the intrinsic and extrinsic eye muscles and their relationship to the acts of accommodation, convergence, fixation, and eye movements. Work in this field is therefore closely related to the sciences of psychology and physiology. The research of the writer indicates that muscle imbalances stand second in importance among the various ocular deficiencies, for in an earlier work using myo-fusion amplitudes as a standard, the writer (3) found that sixty-six per cent out of a group of one hundred college students had muscle insufficiencies.

Although studies in muscle balance were originally associated with conditions of strabismus and heterophorias, the greatest advances have been made in this field because of what one might call the failures or inadequacies of re-

fraction. In recent years, eye practicioners have encountered many problem cases which were unique in that apparently there were no pathological conditions present; the refractive errors were corrected, but still the discomforting symptoms of an ocular disorder persisted.

The increasing number of this type of problem-case served to stimulate investigation into the causes of these ocular discomforts and ultimately led to the recognition of a myological disorder. At first, an attempt was made to remedy these muscle insufficiencies by using prismatic lenses, but in the majority of cases this method has not proved successful (2). However, since the work of Pavlov on the conditioned reflex and the development of the science of psychology, it has been found possible to eliminate these myological troubles by methods of conditioning.

Instrumentation

Among the various instruments that are used for testing such imbalances, the following four machines employ techniques based on the laws of the conditioned reflex:

1. The Arneson Squint Corrector.
2. The American Optical Company Stereo Orthopter.
3. The Wottring Rotoscope, and
4. The Keystone Tel-eye-trainer and Telebinocular.

The squint corrector is a revolving disk target which is used either with the phoropter or with pairs of prisms mounted in handles which may be held by the patient. The stereo orthopter is constructed on the principle of the Wheatstone Stereoscope with a pair of motor driven, swinging mirrors which simulate the effect of prisms. The other two instruments are constructed on the principle of the Brewster Stereoscope with lenses mounted in the head piece. The rotoscope has a pair of motor driven stereoscopic rotating targets, while the telebinocular is essentially a regular stereoscope with a battery of picture cards, geometric designs and incomplete pictures. The tel-eye-trainer is merely the telebinocular inclosed within a hood and with an elaborate motor driven flashing attachment for furnishing light and dark stimulation.

In addition to the above mentioned instruments which employ conditioning methods, there are several that use techniques of flashing stimulation with various wave lengths of light. According to the advertisements of some of these machines, the results are almost instantaneous as compared

with the more prolonged methods of conditioning. However, the "sight unseen" policy under which some of them are sold and the secrecy surrounding the techniques or methods of treatment make it impossible to determine the reliability of these instruments. Furthermore, the technique of one of them is founded on the now discredited "sciences" of Phrenology and Physiognomy.

The writer has had some experience with the above mentioned type of stimulation with various wave lengths of light* and firmly believes that if these methods were carefully investigated, some valuable techniques could be devised. However, it is quite essential that the problem be carried out under medical supervision because this type of stimulation is so powerful that it affects some, if not all, of the endocrines of the human body and may either stop the menses or interrupt the ratio of periodicity (10).

Summary of Discussion on Muscle Balance

Although second in importance among the three main groups of ocular disorders, the problem of muscle imbalances is the youngest in the present field of eye deficiencies which are treated by the practicioner. The subject is yet

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* Unpublished data of earlier investigation by the writer.

so new that it is inadequately presented in the curricula of our professional schools, and most of the contributions from research have been made in private practice and not in the academic laboratory.

Some remarkable results are being obtained by different investigators, but thus far they have been unable to perfect a simple yet adequate technique which could be used by the average practicioner.

Relation of Conditioning Methods to Visual Acuity

Although orthoptic or muscle balance treatments were originally intended for the purpose of relieving the neuro-motor conditions which cause ocular discomfort, it should be noted that in recent literature, the term "Orthoptic Training" has come to include practically any form of exercize or treatment (exclusive of medical or surgical) which is used in the correction of ocular disorders.

A few investigators have noticed that in addition to relieving these neuro-motor disorders, other ocular changes occurred simultaneously. Brief mentions or inferences have appeared in the literature to the effect that "vision could be improved by training or exercizing." More definite references have been made in the bulletins published by vari-

ous instrument companies (4). However, since these accounts were rather vague as to case history, clinical observations, and methods of procedure, they are of little value scientifically.

In his recent text Arneson (2) states quite definitely that vision may be improved by exercizes; instances are cited and data are presented from his various cases. However, these instances cited by Arneson were of pathological cases or conditions with heterotrophias, and, as such, had no immediate bearing on cases in which low visual acuity was among the primary troubles.

Even in the realm of pure science, the possibilities of improving visual acuity is only alluded to by the various writers. Zoethout (12) vaguely refers to the statement by Gaine that "... visual acuity can be increased by practice." According to Firth (6):

> "Another point in regard to a theoretical investigation of visual acuity ... is the psychial aspect of the problem ... from the frequency of cases presenting abnormally high or abnormally low visual acuity ... it would appear that within limits the form sense will respond to training. A good example ... is seen in the steady improvements which can be obtained in suitable cases of amblyopia-ex-anopsia ..... we frequently see an improvement ... from a condition of practically nothing to one which is almost fully normal."

Although Firth mentions that visual acuity can be improved, he gives no experimental data, nor does he refer to any investigations.

The publications of Kravkov (9) and of Hartmann (7) have shown that the visual acuity of one eye could be improved either by stimulation of the other eye or by simultaneous stimulation with sound. However, since these workers were primarily interested in bi-sensual summation, their investigations have little bearing on the immediate problem.

STATEMENT OF PROBLEM AND THE PRELIMINARY INVESTIGATION

Statement of the Present Problem

Although the need for such an investigation is increasing, a survey of the literature reveals no instance wherein research has been done for the specific purpose of finding an effective clinical method of improving visual acuity. The stress of our modern civilization, and ever growing demands of competition, as well as of public safety, have led to the establishment of visual standards for driver's licenses, aviator's licenses, factory workers, civil service employees, and workers in other lines of endeavor. In those fields where such standards cannot be established, the worker with efficient accurate vision will nevertheless, have a distinct advantage.

Since this is an important factor in the field of applied optics the objective of improving visual acuity has been made the goal of this investigation. Briefly stated,

our problem is to see if it is possible to improve the visual acuity by the present methods of conditioning the intrinsic and extrinsic muscles of the eye.

Preliminary Investigation - Subject I

Introduction. With this definite objective in mind the writer set about to find a desirable subject, for it was essential that in addition to having a suitable ocular defect, the person should also be both willing and able to devote the time necessary to carry out such an investigation. Fortunately, an ideal case soon presented itself, a former patient whose past clinical record was readily available, and who was intensely interested in having his visual acuity improved.

The case in question was undertaken with the specific hope of enabling a college student to pass the naval air corps examination. The subject was a senior in the department of Mechanical Engineering, and for approximately four years it had been necessary for him to wear glasses to correct a pronounced error of myopic astigmatism. He wished to join the air corps after graduation, but knowing that his vision without glasses was below normal he consulted the writer in order to ascertain whether he could

see well enough to pass the examination.

Primary Analysis. The subject was wearing the following Rx. which had been prescribed for him a year before:

OD. - .75 axis 15°.

OS. - .75 axis 180°.

The visual acuity with his glasses was 20/20 OD, OS, and OU, but without his glasses was only 20/30 OD, 20/40 OS, and 20/30 OU*.

The muscle amplitudes measured -10Δ, and +20Δ**, the latter of which should have been at least three times stronger. The sense of depth perception was only twenty-five percent as measured on card DB 6 of the Keystone diagnostic series.

Procedure. Since the subject's positive fusion amplitudes were only one third as strong as they should have been, and he failed on the Keystone stereopsis test, it was believed that his vision and sense of depth perception might be improved by increasing the fusion amplitudes. Treatments were started immediately for there were only about three months until the date of the air corps examination. Exer-

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* The terms OD, OS, and OU refer to the right eye, the left eye, and both eyes respectively.

** The sign delta signifies the prism diopter, the strength of prism which causes a deviation of one centimeter at a distance of one meter.

cizes were given with the dumb-bell prisms and Arneson Squint Corrector for periods of forty-five minutes every other day. These were supplemented by home exercizes on a specially constructed stereoscope using a battery of cards selected from the sets published by Keystone, Welle, Pascal, and others. Periodic examinations were made of the subject's visual acuity and sense of depth perception.

Results. In the course of the treatment, the visual acuity of the naked eyes gradually improved until the line of 20/20 vision could be read with each eye and the line of 20/15 could be read with both eyes together. After ten weeks of treatment the myo-fusion ratios were developed to -20Δ, and +30Δ, while the sense of depth perception improved accordingly*. Card DB 8 of the Keystone series, as well as E 10 of the Wells series could be read perfectly without any hesitation.

Two weeks later this subject took the naval air corps examination; and out of a group of 43 applicants for the service, he was one of the two who were accepted. Six months later after his solo flights were completed, a re-check examination was made. There was no change in the visual acuity, sense of depth perception, or myo-fusion amplitudes as taken from the records at the end of the treatment period. However, during that time he had had no treatments.

* From the Pulfrich Phenomenon we know that stereopsis is dependant upon visual acuity.

Recapitulation.

Treatments started March 1, 1936.

Passed naval air corps examination May 31, 1936.

Table 1. Clinical Results of Orthoptic Exercises of Case I

Naked Visual Acuity	At Beginning of Treatments	At End of Treatments	Six Months Later
OD	20/30	20/20	20/20
OS	20/40	20/20	20/20
OU	20/30	20/15	20/15
Myo-fusion Amplitudes	-10 △ +20 △	-20 △ +90 △	-20 △ +90 △

Explanation
of
Figures 1 and 2

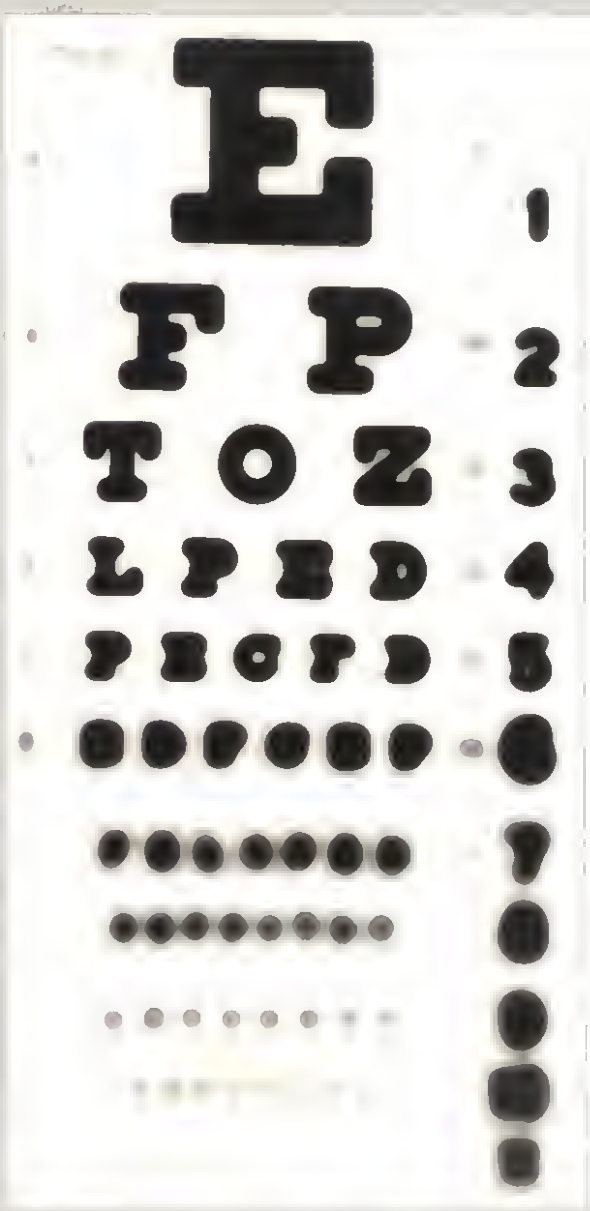

Figure 1.

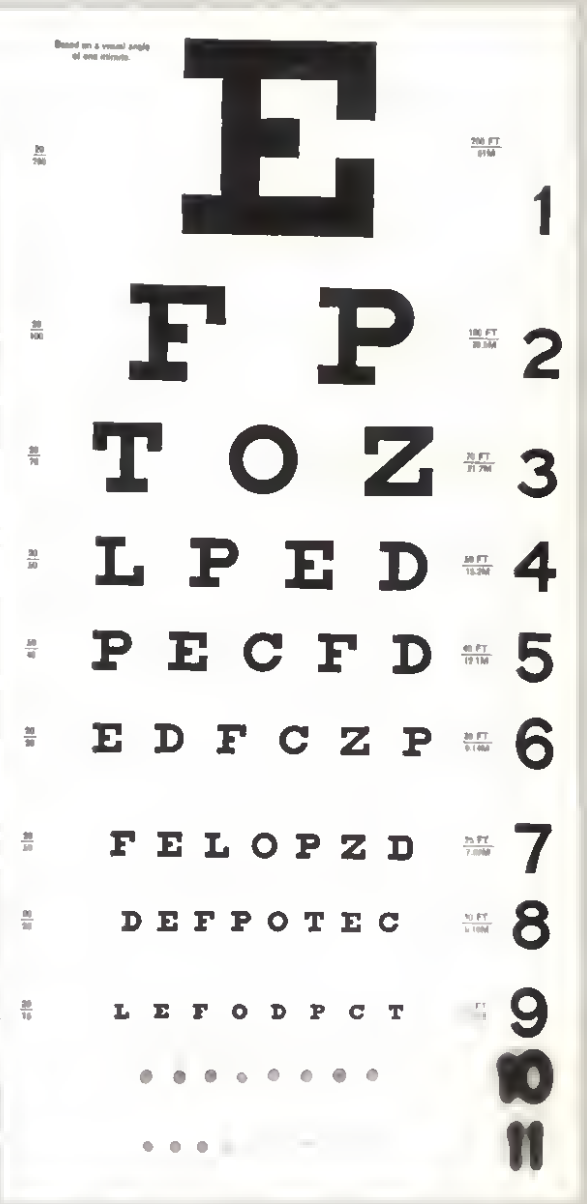

Figure 2.

REPORT OF MAJOR INVESTIGATION - SUBJECTS II TO XII

The success in improving the visual acuity of the preliminary case warranted further investigation in this field. Consequently eleven more patients who might benefit from this work were enlisted for further experimentation. As far as possible, the writer tried to obtain a selection that would represent the various types of cases which are to be encountered in the average practicioner's clientele.

Subjects

Of the subjects who were selected, nine had errors of myopia and astigmatism, two had errors of hyperopia and astigmatism, while another had heterometropia. There was a preponderance of myopic patients in the selection because most low visual acuity cases have myopic errors. The greater percentage of hyperopic patients can usually read better than normal vision.

Procedure

As in the preliminary investigation exercizes were given with the Arneson Squint Corrector and the dumb-bell prisms for periods of forty-five minutes every other day.

Records were kept of the periodic changes in fusion amplitudes and visual acuity. Also, notations were made of any pertinent facts that were observed during the course of treatments.

Subject II

Case History. This person, who was a high school graduate, female, age 18, was attending business college during the time of treatment. For several years she had had eye troubles, and the following symptoms were quite prevalent:

She was extremely nervous and was subject to frequent headaches, pains in eye balls, and severe pains up and down the back of neck. While reading she would experience a drawing or pulling sensation in the eyes, and the type would blur and seem to disappear from the page. The eyes became blood-shot and the lids red and irritated. She had an extreme case of photophobia and the eyes would water easily. At night she was especially troubled with diplopia. Street lights at a distance would appear as two, and the cars would have four headlights.

She was fitted with her first pair of glasses at the age of 14, when a sophomore in high school. These, however, did not relieve the condition, but she wore them for three years.

Primary Analysis. This subject had an error of myopia and astigmatism, but the specialist who fitted her with glasses had given the following Rx. for both eyes: + .25, + .50 axis 90°. Her visual acuity without glasses was 20/200 OD, 20/70 OS, and 20/70 OU. The acuity with the above glasses was unimproved and the discomforting symptoms were increased considerably.

The myo-fusion amplitudes were -5Δ, and +20Δ, and the eye movements were sluggish, a condition which readily accounted for the diplopia at a distance. It was apparent that her glasses were incorrectly fitted and that she was in a miserable condition.

Procedure. A refraction was made and the following Rx. given for both eyes: - 1.50, - 1.35 axis 180°. The visual acuity with this new Rx was improved to 20/60 OD, 20/50 OS, and 20/50 OU. Routine exercizes were given with the squint corrector.

Results. Since this subject was attending business school, her treatment periods were rather irregular. However, within a period of one month her myo-fusion amplitudes had increased above the point of fusional reserve. The painful symptoms had completely disappeared and she was no longer troubled with double vision. At business school her typing speed had been thirty words a minute, and her short-

hand speed fifty words a minute. Within a month these rates had increased to fifty words and one hundred twenty words, respectively. Throughout the treatments the visual acuity gradually improved to 20/20 OD, 20/20 OS, and 20/15 OU with her glasses.

Discussion. In this particular case the trouble was partly aggravated by the glasses which she was wearing. Correct lenses remedied the refractive errors, and the establishing of normal myo-fusion amplitudes eliminated the defective eye movements. Continued treatments developed the ability of fixation, and the sensitivity of the retino-cerebral apparatus was increased by color and flashing stimulation.

Explanation
of
Figures 3 and 4

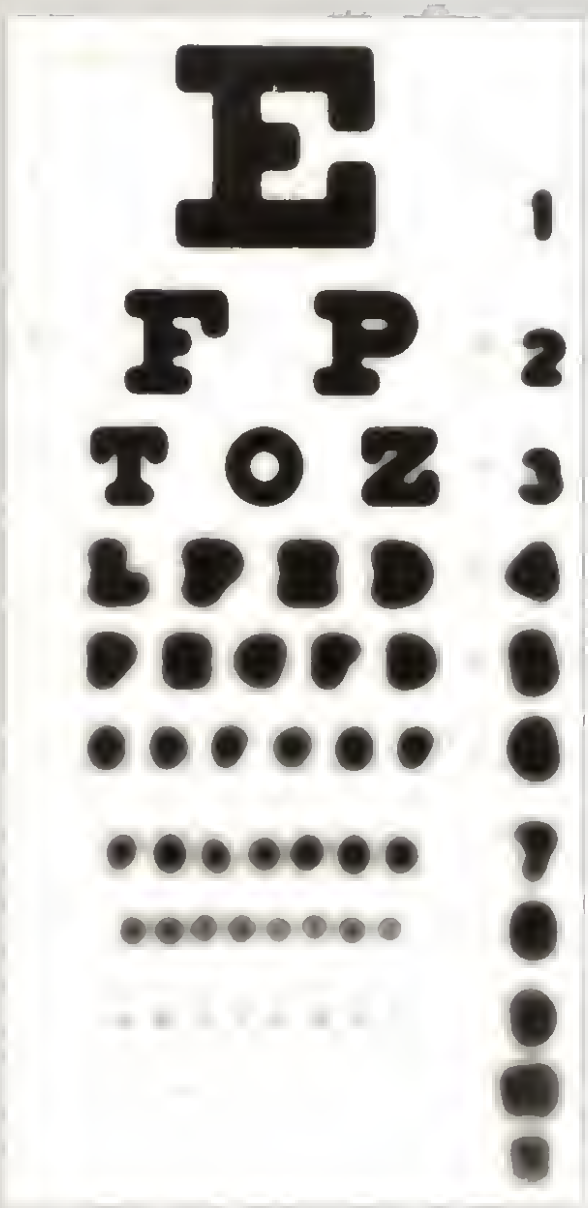

Figure 3.

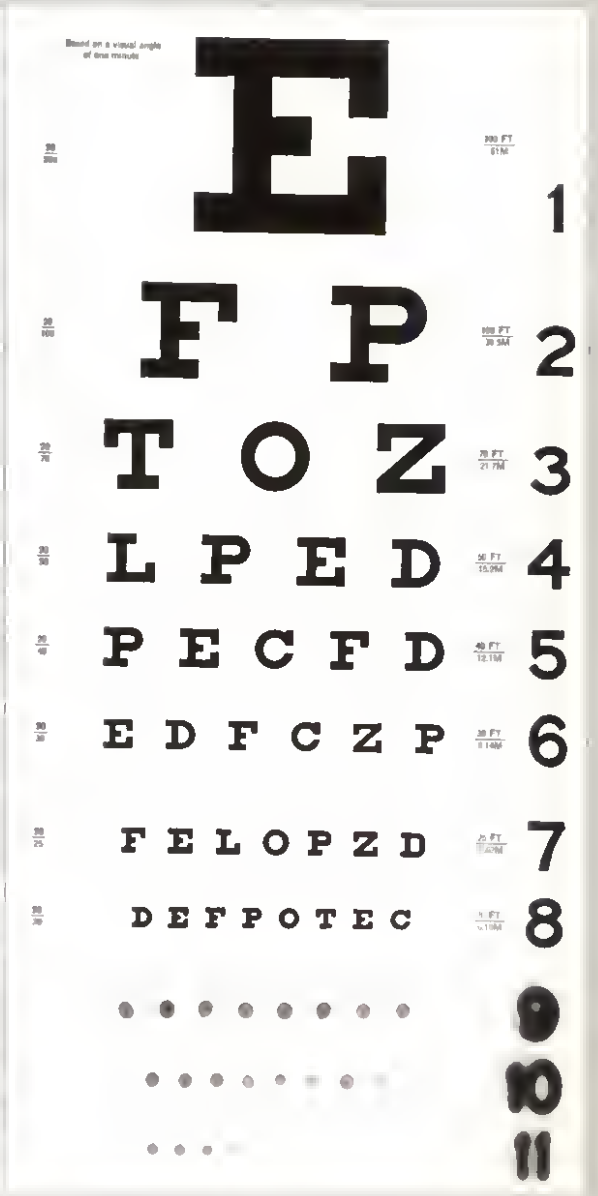

Figure 4.

Subject III

Case History. This subject was a college student, and private secretary, female, age 19. Originally, she had been fitted with glasses by the same oculist who had prescribed lenses for subject number two. The symptoms were similar to those of the preceding subject, with the exception that she had more severe headaches, but was not bothered with diplopia.

Primary Analysis. The naked visual acuity was 20/200 OD, OS, and OU. With the glasses which she was wearing (a pair of spheres + 1.50) the vision was unimproved. The myo-fusion amplitudes measured -5Δ, and +10Δ.

Procedure. A refraction was made, and the following Rx. given for constant wear: OD. - .75, - 1.50 axis 90°.
OS. - .75, - 1.50 axis 115°.

With this Rx. the vision was improved to 20/65 OU. Fusion exercizes were given with the squint corrector to develop both the positive and negative amplitudes.

Results. In this case the treatment periods were irregular because of illness. However, after three months the vision improved until she could read 20/20 OD, OS, and OU, with her glasses. The fusion ratios have developed to -10Δ, and +40Δ.

Explanation
of
Figures 5 and 6

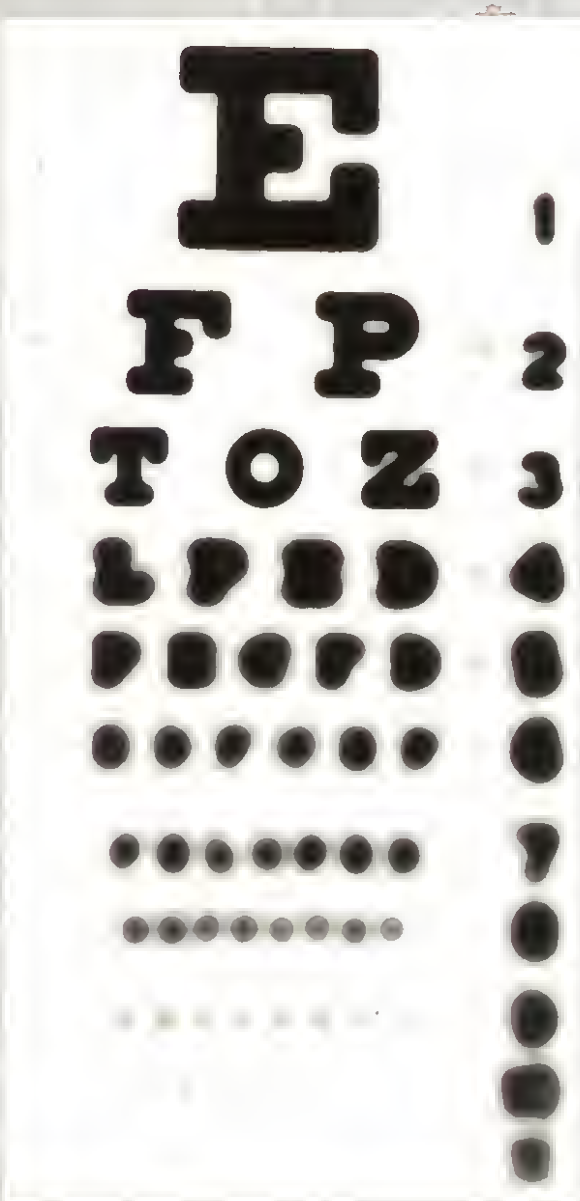

Figure 5.

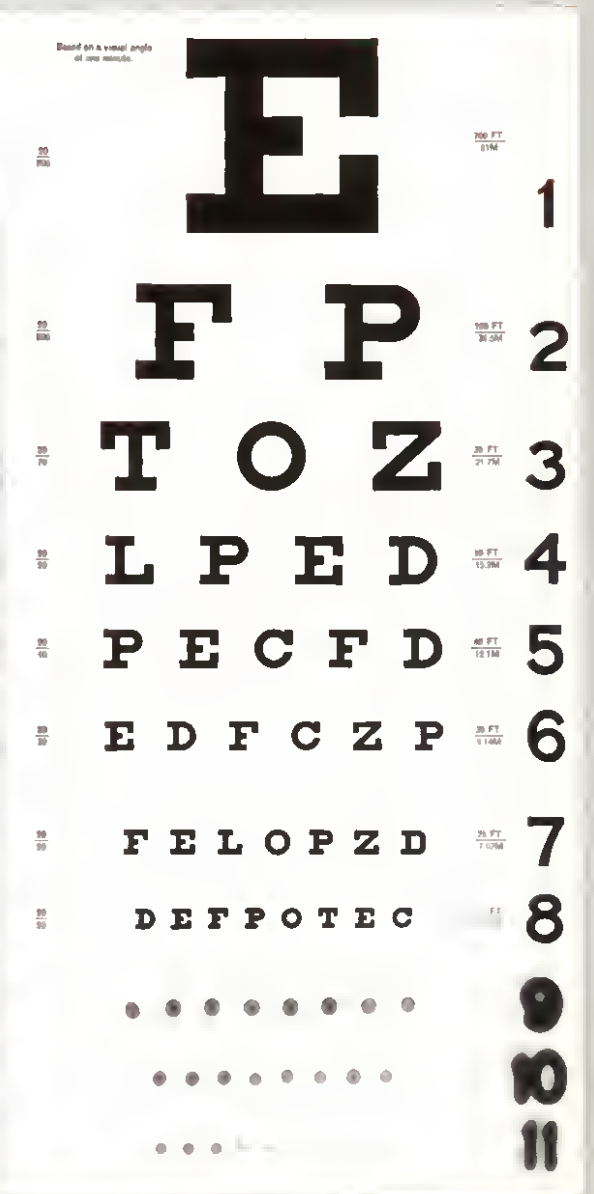

Figure 6.

Subject IV

Case History. A grocery clerk, male, age 29. Since childhood, he had had discomforting symptoms of eye trouble which were similar to those of subjects two and three. He was especially troubled while driving at night. Each car would appear to have four headlights and the glare would be so intense that he would have to stop his car until those approaching passed.

Primary Analysis. At the beginning of the treatment this subject was not wearing glasses. The naked visual acuity was 20/30 OD, 20/30 OS, and 20/25 OU. The myo-fusion amplitudes were -5Δ, and +10Δ.

Procedure. A refraction was made and the following Rx. was given for constant wear: OD. - .37 axis 45°.
OS. - .62 axis 165°.

This improved his vision to 20/20 OD, 20/20 OS, and 20/15 OU. Exercizes were given on the squint corrector.

Results. The painful symptoms disappeared completely within two weeks of the initial treatment, and the subject was no longer troubled with double vision while driving at night. The myo-fusion amplitudes developed until there was an adequate fusional reserve, but there was no change in visual acuity.

Discussion. The vocational factor was important in this case, since the subject used his eyes for very little close work. Also, he was more interested in removing the discomforting symptoms than in improving his visual acuity. As soon as the discomfort was relieved he became irregular in his office calls and eventually stopped taking treatments. Experience with subject number one leads the writer to believe that if this case had continued until the fusion ratios had developed to -20Δ, and +100Δ, the vision could have been improved to 20/10 with his glasses.

Subject V

Case History. This subject was a college professor, male, age 50. Since a child, he had had eye trouble. When a sophomore in high school he nearly failed in his studies, and at that time it was suggested that he wear glasses. During thirty-five years he has had a number of pairs of glasses; some of which were more or less satisfactory, and others which were not.

All through college and the post graduate years while he was working for the Ph.D. degree he was especially troubled with eye fatigue, followed by symptoms of general bodily fatigue. (It might be noted that he was never able to indulge in any sports that involved a contest of endurance). While in school he was obliged to carry light assignments and intersperse his study hours with short naps.

Since that time he has become an authority of world-wide repute in the field of his specialty. However, this was accomplished only through great perseverence while struggling under this ocular handicap. Recently he was called upon to write several text books, and because of this increased demand upon his eyes, they became sensitive to light, bloodshot and the edges of the lids red and irritated.

In the morning, instead of feeling rested, he had a "tired, sleepy feeling" and was troubled with a hyper-secre-

tion of the meibomian glands. He consulted an oculist who diagnosed his case as a pathological condition, and after fitting him with a pair of glasses, gave him some drops to use locally. After a year of taking drops without any apparent relief, he came under the writer's observation.

Primary Analysis. This was a presbyopic case with a condition of compound myopic astigmatism. His visual acuity with the naked eye was 20/200, while his acuity with glasses was 20/30 OD, OS, nad OU. The fusion ratios were -5Δ, and +10Δ.

Procedure. Routine fusion exercizes were given with the squint corrector. During the course of treatments, a refraction was made and a new Rx. was given which increased the acuity to 20/20 OD, OS, and OU.

Results. At the present time of writing, after two months of treatment, the myo-fusion amplitudes have increased to -20Δ, and +90Δ. The visual acuity has improved until he can read the lowest line, 20/10 OD, OS, and OU. The irritated condition of the eyes and eye lids have completely disappeared with the first two weeks of treatment, and the feeling of fatigue has been eliminated.

Discussion. In presbyopic cases such factors as age, general health and physique will limit the amount of possible improvement. The increase of visual acuity in this case was remarkable for a person with such low endurance.

Explanation
of
Figures 7 and 8

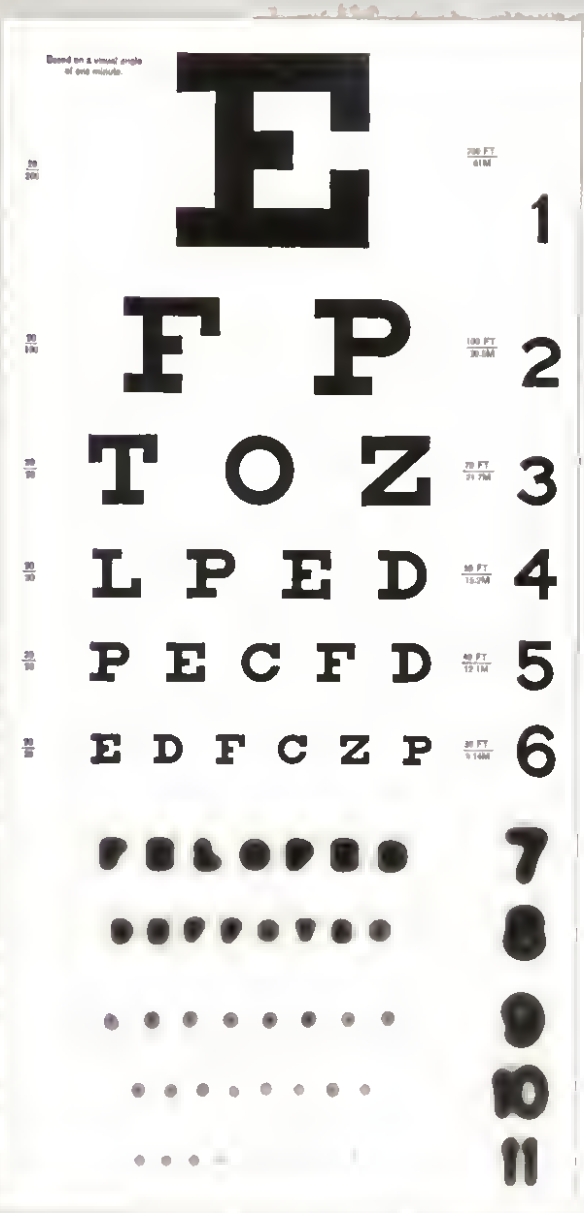

Figure 7.

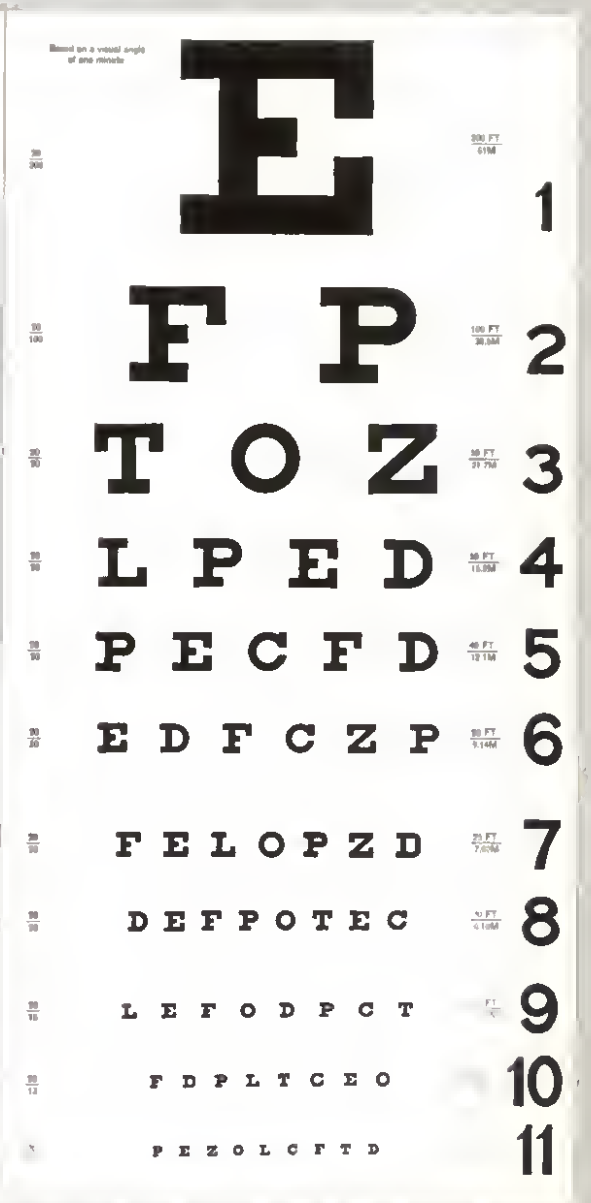

Figure 8.

Subject VI

Case History. This subject was a college professor, male, age 25. He has never had any particular eye trouble, although he first noticed a blurring of vision in the right eye, while taking a health examination in the fifth grade. This condition grew slightly worse until in high school it was necessary that he hold the reading matter quite close to his eyes. He was fitted with his first pair of glasses when he was seventeen years old. These glasses were unsatisfactory so he went to another oculist and obtained a prescription which he wore all through college and the three years of graduate work for his Ph.D. degree.

His parents and two sisters all wear glasses with corrections for compound myopic astigmatic errors.

Primary Analysis. This subject had an error of compound myopic astigmatism in both eyes. His visual acuity without glasses was 20/200 OD, and 20/100 OS. With his glasses the vision was 20/50 OD, and 20/30 OS. A refraction was made and a new Rx. was obtained which increased the visual acuity to 20/40 OD, and 20/10 OS. This was not given for wear at that time.

In the right eye this subject had a condition of relative positive scotoma in the central field, and while looking at a line of letters, the particular letter fixated would appear larger than the rest of them and nearly oblit-

erated by a smudge. However, when fixating on a uniformly plain surface no distortion would be apparent. This scotoma area would seem to increase in size whenever he became tired, and when looking at the sky at night, red spots would appear in the field of vision. The light sense was present in this area because he could fixate on a star. When looking at a pattern, such as quad-ruled paper, he could see the point fixated on, but the immediately surrounding cross-hatching would be distorted. The myo-fusion ratios were - 10Δ, and + 60Δ, the strongest in any case.

Procedure. Fusion exercizes were given with the squint corrector, and alternated with monocular exercizes with flashing stimulation. Vertical diplopia exercizes were also given with the left eye shaded so the right eye could be dominant during the treatment.

After the exercizes had progressed a month, a second refraction was made to test the accuracy of the earlier one. Since there was no change, the Rx. obtained in the first analysis was given for permanent wear. This improved the vision to 20/40 OD, 20/10 OS, and 20/10 OU.

Results. In this case the muscle amplitudes were adequate. After it was explained to the subject that he had to diverge his eyes in order to fuse the target through base in prisms, and to converge to fuse through base out prisms, he readily handled any set of prisms that were given to him

during the treatments. His negative amplitudes were rather sluggish at first but they soon developed up to normal. Within a short time the fusion ratios measured -20Δ, and +100Δ. However, after three months of treatment there was no improvement in the visual acuity.

Discussion. In this particular case the defect was in the refractive mechanism, for as far as we know there was nothing wrong with the retina. This distortion of light rays was apparently caused by the presence of a body in the vitreous humor, and it is quite improbable that exercize would be of any great help unless the treatment were vigorous enough to displace the object from the field of central vision, or the increased circulation of the vitreous humor would bring about its dissolution.

Subject VII

Case History. Bank clerk, male, age 31. At some time between the ages of three and five, this subject had an abcess in the back of the left orbit. The condition was eventually cured, but the vision of this eye was impaired. The patient has worn glasses for reading purposes at intervals for the past fifteen years. However, he has had no discomforting symptoms of eye trouble. Before he came under the writer's observation, he consulted an ophthalmologist who, after making a thorough examination, advised him to discard the glasses he was wearing and ..."to try exercizing that left eye, it might improve."

Primary Analysis. This subject had an error of compound myopic astigmatism in both eyes, and the naked visual acuity was 20/40 OD, and 4/200 OS. A refraction was made and the Rx. : OD. - .25, - .37 axis 35°. which improved the acuity to 20/10, was given for the right eye. No Rx. was given for the left eye at that time.

Procedure. A blank disk was placed on the right eye and this combination was given for wear during all periods when he was not at work. Exercizes were given on the squint corrector. At first the left eye was unable to discern the colors on the disk, but after two or three treatments this ability was restored.

Clinical Observations. As soon as vision was developed to the extent that a diplopia could be produced, the phorias were measured and it was found that this subject had a case of left hypotrophia. The images were then superimposed with vertical prisms, and treatments were continued on the squint corrector.

Results. At the time of writing, after one month of treatment the visual acuity has improved to the line of 4/20. The fusion ratios have developed to -10Δ, and +30Δ.

Explanation

of

Figures 9 and 10

Figure 9.

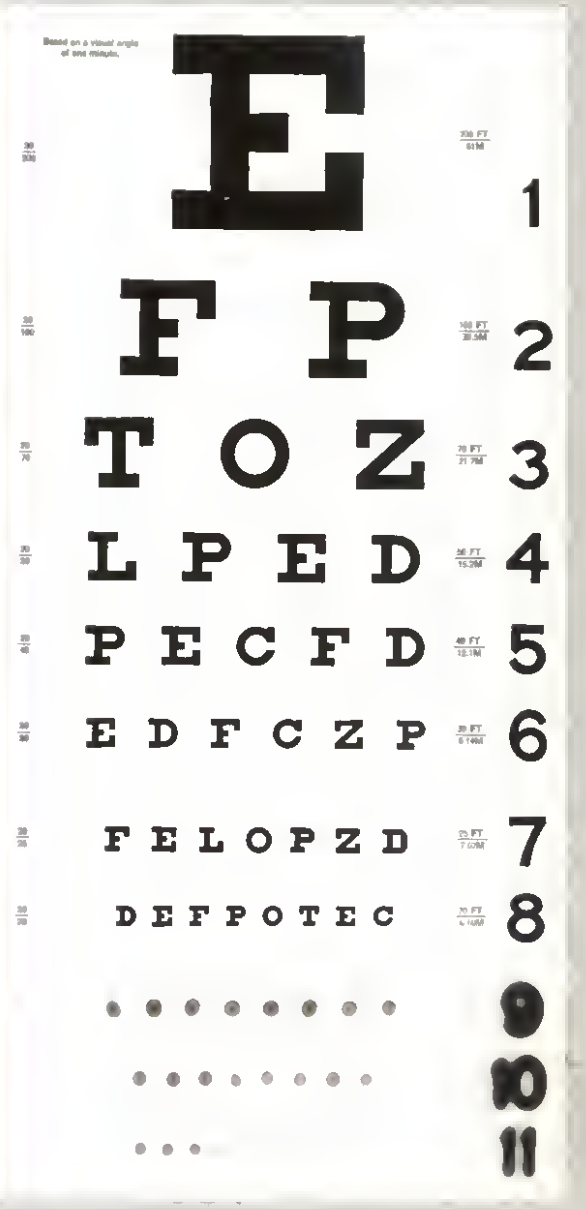

Figure 10.

Subject VIII

Case History. College student, male, age 21, who had been troubled with the following symptoms: He would have pain or ache in the eye balls, and the eyes would become blood-shot and smart or burn. The eye lids would twitch considerably and he would fall asleep easily while reading.

Primary Analysis. The naked visual acuity was 20/60 OD, and 20/15 OS. The fusion amplitudes measured -8 Δ, and +12 Δ. Exercizes were given with the squint corrector.

Results. This particular case was irregular in his treatments, however, within a period of one semester the fusion ratios gradually improved to -20 Δ, and +100 Δ. There was no marked change in visual acuity, although the Rx. changed from a +1.25 sphere before the treatments to the following Rx. afterward:

OD. - .75,

OS. , - .50 axis 25°.

Subject IX

Case History. This subject was a rural school child, age , who had an error of compound myopic astigmatism, and an extreme degree of hyper-divergent strabismus in the right eye. Her eye had been in this condition ever since she was a year old. It had been customary for the mother, while she was going about her house-hold duties, to place the child's crib away from that portion of the room wherein she was working. Consequently, in order to watch its mother, the baby had to look upward and backward over its head. The writer believes that this was one of the contributing factors of the condition.

Primary Analysis. The naked visual acuity measured 20/200 OD, 20/40 OS, and 20/40 OU. A refraction was made and the following Rx. was given: OD. - 1.50, - .75 axis 70.°

OS. - , -1.50 axis 160.°

Procedure. In this particular case a blank disk was placed over the right eye for constant wear, and since the subject lived too far from the office to come for daily treatment, a squint corrector was loaned to the family for home use. With this arrangement, the child had two half hour exercises every day. Office calls were made once each week, and the eyes were carefully checked for changes in refraction. As soon as constant diplopia was established,

the images were superimposed with prisms and the treatments continued. Since the eyes were divergent, only positive fusion exercizes were given.

Results. Within the course of the treatments, one year, the visual acuity of both eyes had developed to 20/20 OU with glasses. At the time of writing the eyes were perfectly straight both with and without the glasses, and the positive fusion amplitude was 40Δ.

Discussion. In this case the writer was fortunate that the subject was living with her aunt who was very diligent in seeing that the youngster had two exercizes every day. It should be pointed out that in strabismus cases especially, the greater part of the work must be done by the patient. It is true that this case might have been straightened by an operation, but the vision would not have been restored except through exercize.

Explanation
of
Figures 11 and 12

Figure 11.

Figure 12.

Figure 13.

Figure 14.

Subject X

Case History. This subject was a school child, female, age 13. She had no discomforting symptoms of eye trouble, but the vision of the left eye was practically extinct. Her parents had taken her to several oculists, all of whom said that nothing could be done for her, and that she would eventually go blind. Her younger sister had a pronounced case of divergent strabismus, and both parents wore glasses for the correction of hyperopic defects.

Preliminary Analysis. The subject, who was near sighted in the right eye and far sighted in the left eye, was wearing the following Rx. : OD. - 1.00,

OS. + 5.00

Her naked visual acuity with the right eye was 20/65, while the left eye could only distinguish light and dark. With her glasses on, the acuity of the right eye was 20/30 but the left eye was unimproved. The myo-fusion amplitudes were - 5 Δ, and +10 Δ. There was a pronounced condition of anisocoria* , with a negative Argyle Robertson Reflex** in the left eye. The light reflex of the left eye was also much slower than that of the right eye although the consensual reflex was present.

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* A condition of unequal pupils.
** Pupil reacted to light but not to accommodation.

The eyes were examined for refractive errors, and a new Rx. was given: OD. - 1.75,

OS. + 3.50. + 1.50 axis 90°.

With this Rx. the visual acuity was increased to 20/20 OD, and 20/100 OS. Also, the patient was able to read diamond point number 1 type with the left eye at a distance of four inches.

Diagnosis. Because of the following three conditions, the writer considers this a case of hypertonic contraction of the left ciliary muscle - a locked accommodation:

1. The patient could read perfectly with the left eye as long as the subject matter was held at a distance of four inches.

2. The condition of anisocoria.

3. The negative Argyle Robertson Reflex in the left eye.

Procedure. A blank disk was placed before the right eye and this combination was worn throughout the course of the treatments. Fusion exercizes were given with the squint corrector, and periodic checks were made for changes in the refractive error and visual acuity.

Results. Altogether, three lens changes were made for the left eye during the progress of the treatments:

Original Rx. OS. + 5.00,

First Change OS. + 3.50, + 1.50 axis 90°.

Second Change OS. + 2.50, + .75 axis 70°.

Final Rx. OS. + 1.50, + .75 axis 70°.

Within twelve weeks the visual acuity gradually improved until she could read with glasses 20/15 OD, 20/50 OS, and 20/15 OU. The myo-fusion amplitudes were developed to -10 Δ, and +60 Δ, while her near point reading distance had lengthened to ten inches.

Discussion. Since the primary trouble in this case was a neuro-motor condition, and the left eye was becoming amblyopic, a shield was placed over the good eye in order to make her use the bad one. Unfortunately, from the view point of this research, the child's father who had been on relief, secured a government job in another state, and the family moved away. However, if this case could have been completed, the writer feels that the vision of the left eye could have been developed to a degree equal to the right one.

Explanation

of

Figures 15 and 16

Figure 15.

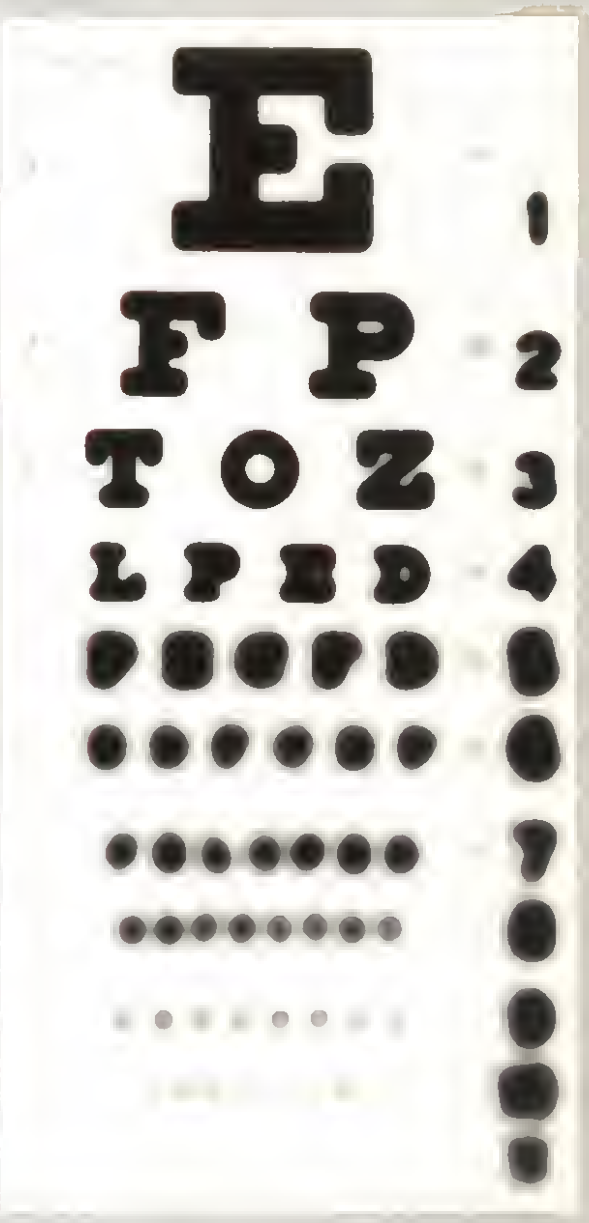

Figure 16.

Subject XI

Case History. This subject was a college student, male, age 22, who had recently transferred from a junior college. He had never had any eye trouble during his pre-college work, but the longer study periods demanded by the heavier curriculum, soon brought out the symptoms of an ocular defect. He would have a pain or ache in the eye ball, and experience a stinging or smarting sensation in the eyes. His eyes or eye lids would twitch and he would fall asleep while studying.

Primary Analysis. The naked visual acuity was 20/40 OU. A refraction was made and the following Rx. given:

OD. + .87, + .37 axis 65°.

OS. + .62, + .50 axis 105°.

This improved the visual acuity to 20/25 OD, OS, and OU. The myo-fusion amplitudes measured -10°, and + 15°.

Procedure. Exercizes were given on the squint corrector, and periodic checks were made for changes in vision.

Results. After twelve weeks, the myo-fusion amplitudes were improved from -10Δ, and +15Δ, to -20Δ, and +100Δ. The visual acuity with his glasses was improved to 20/15 OD, OS, and OU.

Subject XII

Case History. College professor male, age 47. For the past fifteen years this subject has had eye trouble, but was never able to obtain any glasses that would relieve the condition. The principal symptoms were low visual acuity and pronounced asthenopia.

Primary Analysis. A refraction was made and the following Rx. given for constant wear: OD. + .75 axis 90°.
OS. + 1.25 axis 90°.

With this Rx. the visual acuity was improved to 20/30 OD, and 20/40 OS. The fusion amplitudes measured -7Δ, and +20Δ. Routine exercizes were given on the squint corrector.

Results. This case was not completed at the time of writing, however, within a period of six weeks the myofusion amplitudes had increased to -20 , and -70 . The visual acuity with his glasses had increased to 20/20 OD, 20/25 OS, and 20/20 OU. The asthenopic symptoms were almost eliminated.

SUMMARY AND INTERPRETATION OF RESULTS

Summary of Results

I. Of the two cases with simple myopic astigmatism, the visual acuity of one improved three lines, while the other showed no improvement.

II. The visual acuity of all three subjects with compound myopic astigmatism improved five lines in each eye.

III. The case with central scotoma in addition to compound myopic astigmatism showed no improvement.

IV. Of the two amblyopic cases with compound myopic astigmatism, one was improved seven lines at a distance of one meter, while the other case has shown no marked improvement.

V. In the heterometropic case, the acuity of the hyperopic eye was improved from legal blindness to four lines on the test chart. The acuity of the myopic eye was improved three lines.

VI. In the strabismus case with compound myopic astigmatism, the visual acuity was improved seven lines and the divergent eye was completely straightened.

VII. In the two cases of compound hyperopic astigmatism, the visual acuity of both eyes improved two lines.

Discussion of Visual Acuity Factors Basic to the Interpretation of Results

The phenomenon of vision is the resultant of a number of complex physical, physiological, and psychological processes which occur within the following four anatomical or structural systems:

1. The refractive system of the eyes which is analogous to the camera and is essentially physical in its action.

2. The retino-cerebral tracts.

3. The myo-neural system which contributes to the eye movements.

(Both two and three are pirmarily physiological in their function).

4. The interpretive mechanism of the cerebrum, which is chiefly psychological in its processes.

Thus, the act of vision will be affected by the degree of perfection of the refractive system, the sensitivity of the retino-cerebral tracts, and the efficiency of the myo-neural system, as well as the patterns of the engrams or neurograms of the cerebrum.

There are three additional factors which are dependent upon the retino-cerebral tracts and the interpretive mechanism of the cerebrum, and which place a limit upon the

degree of precision of the human eye:

1. The light sense, or the minimum visible; also called the visual sense of position. This is the primary function of the eye.

2. The resolving power of the eye, or the minimum separable, which is sometimes called the sense of discrimination.

3. The vernier or contour acuity of the eye, which is the power of the eye to detect the condition of break or alignment between two lines.

The Minimum Visible. According to definition, the light sense or minimum visible is the smallest area of the retina which will respond to the threshold stimulus from a point source of light - the threshold stimulus being that minimal quantity of light which excites a small group of cones.

It should be noted that the minimum visible is quite variable in its magnitude, and that according to Adler (1) it is "impossible to define the threshold of the light sense in terms of the visual angle."

According to Ricco's law of foveal vision (8), at the threshold of visibility, the product of the area stimulated and the total amount of light is constant up to an angle of two degrees. Consequently, it can be readily seen that such

factors as the intensity of the stimulus, the adaptation of the retina, and the contrast with the back ground will readily affect the size of the area stimulated.

The Minimum Separable. The resolving power of the eye, or the minimum separable, may be defined as the ability to discriminate between two points of light - that is to perceive two points of light simultaneously and to recognize them as being separate. This ability is limited by an anatomical factor - the size of the cones of the retina. In the fovea a separate nerve fiber is connected with each cone. Consequently, if the two separate points of light fall either on one cone or two adjacent cones, a single impression is the result. However, if the two images fall on two cones separated by a third cone, the observer will perceive two points of light. Extensive investigation has shown that the minimum separable, or the resolving power of the eye, is approximately one minute angle of arc (1) .

The Vernier Acuity. The vernier acuity, or aligning power of the eye is the ability to perceive lateral variations in the position of a line. According to Adler (1) "It is probably the most acute of human senses ... the aligning power can be twenty times as delicate as the resolving power ..."

Numerous explanations have been presented to account

for this extreme degree of sensitivity of the eye, but the theory advanced by Anderson and Weymouth appears to be less open to criticism than any other. Although a detailed explanation of their work is outside the scope of this paper, the following summary as quoted by Adler, is pertinent to the present problem:

> "The fineness of perception with the two eyes working together depends upon three factors:
>
> 1. The mutual effect of the adjacent retinal elements in either retinae, i.e., the retinal mean local sign.
>
> 2. The averaging of successive stimulus patterns on each retinal mosaic caused by the constant slight eye movements.
>
> 3. The combining of the two simultaneous stimulus patterns placed to the two eyes, i.e., fusion.
>
> As a result of these three factors the aligning power of the eye may be so acute that a disparity between images of a fraction of a cone diameter may be clinically perceived."

Visual Acuity. The visual acuity or form sense has been designated by Zoethout (12) as the "minimum legible or cognoscible." , and it is still a disputed question as to which of the foregoing factors this ability is dependent upon.

Zoethout goes on to say:

> "While it is dependent upon the minimum visible and the minimum separable, the minimum legible is the result of much more complicated physiological and more especially psychological processes."

According to Adler:

> "A great many factors which are purely psychological enter into the acuity of space perception, ... The chief underlying physiological factor, however, is the so-called aligning power of the retina. ... When we judge an individual's vision by our standard clinical tests we are investigating both the resolving power and the aligning power of the eye ..."

The writer feels, however, that visual acuity is dependent upon all three of the above factors as well as certain psychological factors which will be mentioned later. This point of view is well exemplified in the following illustration given by Adler:

> "When a card containing the letter E in different positions is looked at from quite a distance, the card may seem perfectly white ... the irradiation of the white surface is so great on the retina that the value of the light on the whole retinal surface involved is higher than the threshold value of all the cone units; they all respond therefore, and the card seems uniformly white. As the card is brought nearer a point is reached where the letter is large enough to cause a perceptible difference in the light intensity falling on some of the cone units. The light on these units falls below the difference threshold and we become conscious of spots on the card."

At the above mentioned point where the spots are first seen, the writer believes that the minimum visible comes into play, yet Adler makes no mention of this factor. Continuing, Adler says,

> "If the card is brought still closer ... we can see that one side of the figure looks lighter than the others. At this point we begin to use the aligning power of the eye... A little closer and we recognize the figure as an E. The thresholds of the aligning power and the resolving power of the eye have been passed and now the detection of form depends largely upon psychological factors."

Interpretation of Results

Since the phenomenon of vision is the resultant of a number of complex processes which occur within the above mentioned anatomical systems, it is evident that if visual acuity is to be improved, one or more of these systems must be affected, and probably any one or more of the following changes may occur:

I. There may be a change in the dioptric power of the refracting mechanism of the eye.

II. The sensitivity of the retino-cerebral tracts may be increased.

III. Adequate motor patterns of ocular adjustment may be established.

IV. The acuity of certain psychic factors, such as the power of attention and the fusional ability, may be increased.

I. Changes in Dioptric Power. Because of the interdependent nature of the acts of accommodation and convergence, a deficiency of one is usually associated with an impairment of the other. Furthermore, any exercizes given to improve the myo-fusion amplitudes will simultaneously affect a change in the power of accommodation(1), (12).

Since most of the changes that occur in the refractive condition of the eyes are the result either of maturation

or of a variation in the accommodation, the writer believes that the most marked changes in the dioptrics of the eye will occur in cases in which there is a deficiency in the accommodative power.

A. Hyperopic Cases. Among the subjects employed in this study, the change in the refractive power of the eye was greatest in subject number ten who had a locked accommodation in the left eye. In this case a change of three and one half diopters of spherical power occurred during the course of the treatments. There was not such a marked change in the lens power of subjects eleven and twelve, although they showed an improvement of two lines on the test chart. No doubt this change was brought about by the increased range of accommodation.

B. Myopic Cases. Among the six myopic cases who showed an improvement in visual acuity, all had low negative fusion amplitudes. Since their convergence was unable to relax, a corresponding contraction was maintained in the ciliary muscles. As soon as adequate fusion amplitudes were established, this ciliary contraction was relieved and the focus improved accordingly.

II. Changes in the Retino-Cerebral Tracts. The increase of sensitivity of the retino-cerebral tracts was most pronounced in case number seven. The response to color in-

oreased greatly during the first treatment, and further exercizes served to lower the threshold of the light sense.

The specific factors which bring about an increased sensitivity of the retino-cerebral tracts are yet unknown, but we do know of thres different rocesses which occur within these tracts when light falls on the retina:

A. Changes in the chemical reaction of the retina, including metabolism and the vitamin A - rhodopsin cycle.

B. The mechanical effects (migration of the rods and cones) which take place on exposure to light, and

C. The electrical phenomena that occur in the retina and the optic nerve.

A. Chemical Changes that Occur in the Retina. Since the substances involved and the end products liberated are much the same in the retina as in the muscle fibers, Lange and Simon have formulated a photo-chemical theory which is similar to the changes that are thought to occur during muscle action (1).

With regard to the visual purple cycle in the retina, the recent work of Wald (11) shows that rhodopsin is a conjugate protein with vitamin A as one of its components. It is briefly stated as follows: Vitamin A is carried by the blood stream to the retina where it combines with certain proteins to form rhodopsin or visual purple. When exposed

to light. visual purple changes to visual yellow which in turn breaks down into vitamin A and various colorimetric products. This reaction goes on in a continuous cycle.

We are uncertain as to the exact bearing which these chemical changes have on the act of vision, but if it is a photo-chemical reaction in the retina which brings about the corresponding impulse in the optic nerve, continued stimulation of such reactions would no doubt affect a lowering of the visual threshold in cases with poor visual acuity.

B. Migratory or Mechanical Changes. According to Zoethout (12), as early as 1867 Czerny found that in an enucleated eye which had been previously dark adapted, the epithelial membrane could be easily separated from the layer of rods and cones. In the light adapted eye, however, it was impossible to separate these two layers. When exposed to light, the inner limbs of the cones contract while the rods extend. This change is not only brought about by an external stimulus, but it may be caused by an internal stimulus as well.

According to Adler:

> "There is evidence that light thrown into one eye will affect the cones in the other eye ... and it has been shown that retino-motor impulses pass down the optic nerve from the brain to the retina."

A similar reference has been made by Zoethout to the

effect that,

> "The actual existance of efferent fibers in the second cranial nerve has been demonstrated by Cajal .."

These migratory changes are closely related to the state of dark and light adaptation of the eye as well as to the visual purple cycle. Consequently, since it usually takes from thirty minutes to an hour for the eye to become completely dark adapted (1), there is probably very little structural change either in the rods and cones or the pigment layer that is brought about by brief intervals of stimulation. However, since efferent fibers exist in the optic nerves, it is possible that stimulation of one eye might bring about an increase in the sensitivity of the other.

C. Electrical Phenomena. With reference to the electrical changes that take place in the eye ball itself, there are two types of currents, the demarcation current and the action current, both of which have been demonstrated.

According to Adler:

> "If the eye ball ... is connected with a galvanometer by two electrodes, with one electrode on the cornea, and the other placed anywhere on the globe back of the ora serrata, this so-called demarcation current will be found. In this case the cornea is always positive and the posterior half of the globe negative."

With reference to the action current, Zoethout says,

> "The entrance of light into the eye causes a change in the electrical condition of such a nature that the layer of rods and cones is electrically negative towards the nerve fiber layer or the optic nerve."

In addition to the demarcation and action currents of the eye ball and retina, there are action currents in the optic nerve.

In continuing, Adler says,

> although, "... the optic nerve ... is not a peripheral sensory nerve, but a part of the central nervous system, ... the close resemblance of the electrical responses from the optic nerve with those of any nerve of common sensation are quite striking."

Apparently these electrical phenomena are associated with the transmission of the nerve impulse from the retina to the cerebrum. It is probable that continued application of any stimulus which would give rise to these phenomena would serve to increase the sensitivity of the retino-cerebral tracts.

III. Changes in the Motor Patterns. In every case new oculo-motor patterns were established as shown by changes in the fusion amplitudes. These contribute to the improvement of visual acuity by enabling the eyes to fixate properly and thus allowing the images to fall on corresponding retinal points. This establishes the optimum conditions in order that binocular summation may take place.

IV. Psychic Factors. Closely related to the motor patterns of the eye are the psychic factors of vision. If the fusion amplitudes are low, the visual factors of attention can hardly be at a maximum because of retinal rivalry.

However, when adequate fusion ratios are established, the retinal rivalry is greatly reduced and the factor of attention will be improved accordingly.

CONCLUSIONS

In certain types of non-pathological cases with subnormal vision:

1. Visual acuity can be improved by orthoptic exercizes with the Arneson Squint Corrector.

2. There may be a change in the dioptric power of the eye, depending on the type of ocular defect.

3. The sensitivity of the retino-cerebral tracts may be increased.

4. The degree of improvement which can be made in each case depends upon clinical conditions and the attitude of the patient.

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